Limits for the perception of directional dependence of the reverberant tail in Binaural Room Impulse Responses (BRIR)

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Introduction

Sound perceived in typical reverberant environments depends on the signal-source and the acoustics of the environment as well as the shape of the outer ear. In a room, we hear the convolution of the presented sound and the Binaural Room Impulse Response (BRIR), which contains all the acoustical information of a room and the outer ear. The reverberation can be separated in different parts. The first part, containing some high level peaks, includes directional information. The second part is a diffuse tail without directional information, consisting of many decorrelated reflections.
Since the BRIRs are recorded with a dummy head, it is possible to present the spatial information over headphones. In this psycho-acoustical experiment, the perception of BRIRs has been surveyed with regard to head orientation. The Perceptual Mixing Time (PMT) [2], which is the point where the BRIR starts to get diffuse, has been measured by manipulating real BRIRs.
Investigating the strength and duration of directional inforamtion in BRIRs is important to understand the correlations of physical parameters and room acoustical perception. Therefore knowing the boundary of directional information in the BRIR is an important step to predict the perception of room acoustical parameters with a model [3].

Method

For the experiment, the BRIRs have been manipulated by exchanging the diffuse tail of the reverberation [1]. The first part of an original BRIR has been combined with the diffuse tail of a "foreign" BRIR, recorded in the same room at the same position, but with another head orientation. The cross over was realised by cosine-shaped ramps, which guarantees a constant level of energy for the addition of uncorrelated signals. Figure 1 shows an example for thes window functions which were multiplied with the impulse responses. The point where both lines cross was the measured variable of the experiment.

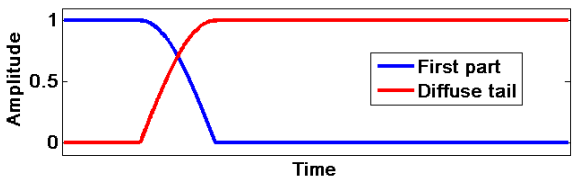

Figure 1: Window functions multiplied with BRIRs for different head orientations. The first part of one BRIR was combined with the diffuse tail of another. The changeover, realised by cosine ramps, was shifted during the experiment.

The BRIRs used for this experiment were recorded in a lecture hall of the TU Berlin with a FABIAN dummy head. The Sound was presented with a Dodekaeder-speaker and the room had a reverberation time (T_{60}) of 1.45 s. Three different combinations of manipulated BRIRs were compared with their corresponding originals. Table 1 gives an overview of the tested combinations.

Table 1: Combinations of manipulated BRIRs and their corresponding originals

head orientation		
original	first part	diffuse tail
0°	0°	40°
-40°	-40°	0°
80°	80°	0°

An original BRIR from the front (0°) was compared with a manipulated one combined of a first part also from the front but a diffuse tail from the right (40°). BRIRs from the left (-40°) and right (80°) were manipulated with a diffuse tail from the front (0°) and compared with their originals. The length of the cosine-ramps for the cross eover was 6 ms. The impulse responses where 2.9 s long and for the test, they where convolved with three second long parts of a music signal, recorded in an anechoic room. The music signals where a specific excerpt parts of a guitar and a snare drum play. Six normal-hearing subjects participated in the experiment and the six different conditions (three combinations of impulse responses for two different instruments) were presented in a random order.
The psycho-acoustical paradigm was a two-Interval two-Alternative-Forced-Choice procedure. The first interval served as reference and always contained the original (unmanipulated) signal. The second interval was randomly selected and was either the original or the corresponding manipulated signal. The task for the subjects was to detect if the second interval differed from the first one. If the subjects answered correct, the cross over point was shifted to a later point of the BRIR, thus the difference between original and manipulated signal was decreased. If the subjects answered wrong, the changeover was shifted to an earlier point of the BRIR to ease the discrimination of original and manipulated signal.
A 2-up 1-down proceedure was chosen, thus two consecutive correct answers were needed to increase the cross over point. The starting variable was 40 ms. the stepsize was adapted logarithmically to the time of the changeover and was reduced down two 4 ms during the measurement phase. The resulting thresholds for the

PMT were calcualted as a mean of the last six reversals for each condition. Every subject had to repeat the experiment three times and the first run was regarded as training and not considered for the analysis.

Results

Figure 2 shows single results of the measured PMT for the two different music instruments (guitar - red diamonds, snare drum - blue circles) for the three different head orientations of the original (0°, -40°, 80°). The errors are the standard deviation for each measurement. The plotted time describes the threshold in the BRIR where the manipulated stimulus would just be discriminated from the original signal. Some subjects were not able to detect any differences between original and manipulated signal for all the conditions. In these cases no threshold could be measured. Those results are plotted as 0 ms. The results are widely spread over the time

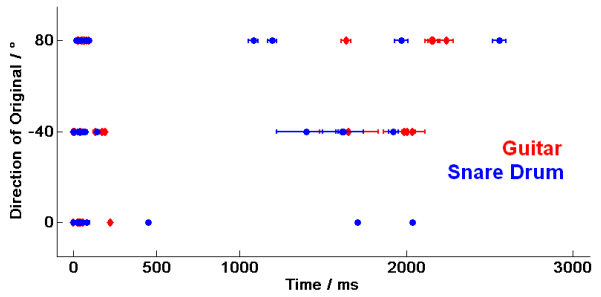

Figure 2: Single results of the measured Percetual Mixing Time (PMT) for two different music signals (guitar - red diamonds, snare drum - blue circles) convolved with BRIRs for three different directions of head orientation (0°, -40°, 80°).

axis but can be separated in two groups. All the results for the second group (large mixing times, above 300 ms) originate of two subjects. Both are musicians and they reported after the measurement that they focussed on small tonal cues like resonances or beats, to determine between the two signals. Those cues where not percecptible for the other subjects and even the two "experts" were not able to use them in every condition. It is remarkable that in some cases the subjects still were able to perceive those tonal cues even when most of the BRIR consisted of the original.

Other used cues to distinguish between original and manipulation where binaural cues. Subjects reported spatially expanded soundsources or even the perception of more than one source in the manipulated signal. Those results are combined in the first first group (smaller mixing times, below 300 ms) and are shown in detail for a smaller interval of time in figure 3. Additional to the single results the mean values of the first group (results of 0 ms excluded) are shown in black.

The results of the first group show an area of about 30 to 100 ms for the threshold for the PMT. The PMT seems not to depend on the orientation of BRIR and no clear differences between both instruments can be seen. The mean PMT and corresponding standard deviation for all conditions for this room with a reverberation time (T_{60}) of 1.45 s are 60 ± 14 ms.

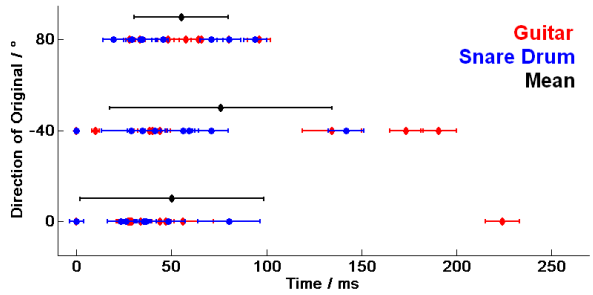

Figure 3: Detailed plot of the first group of single results of the measured Percetual Mixing Time (PMT) for two different music signals (guitar - red diamonds, snare drum - blue circles) convolved with BRIRs for three different directions of head orientation (0°, -40°, 80°). Mean values for the results of the first group (results of 0 ms excluded) are shown by the black diamonds, error bars represent the standard deviation.

Conclusion

The results of the experiment show that different room acoustical parameters were affected by the manipulation we performed. Subjects did not focus on just one perceptible cue but appeared to use different cues to perform the discrimination task. By grouping the results according to the cues the subjects reported to have used, it is possible to focus on the binaural perception. Those results show, that there is an area of time in which the differences in spatial information in BRIRs stop to be perceptible. Thus, it should be possible to generate a common diffuse tail of a BRIR for different head orientations in a room, without creating the impression of an implausible spatial perception of a room.

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